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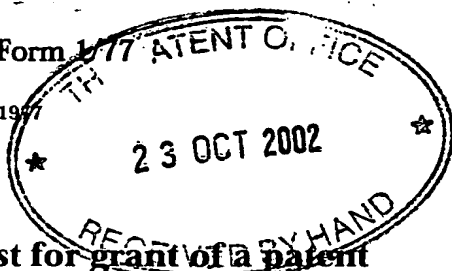
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1. Your reference NRJ/P34705GB

2. Patent application number
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0224714.6

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Switched Reluctance Drives Limited,
East Park House, Otley Road,
Harrogate, North Yorkshire HG3 1PR,
England.

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

England.

7010713001

4. Title of the invention

ELECTRO-MECHANICAL TRANSMISSION SYSTEMS

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Kilburn & Strode
20 Red Lion Street
London
WC1R 4PJ

Patents ADP number (if you know it)

125001

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 - b) there is an inventor who is not named as an applicant, or
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Continuation sheets of this form

Description 12

Claim(s) 5

Abstract

Drawing(s) 1 *ti* *th*

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

Request for preliminary examination and search (*Patents Form 9/77*) 1 *—* *th*

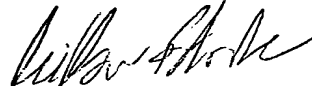
Request for substantive examination (*Patents Form 10/77*)

Any other documents
(*please specify*)

11.

I/We request the grant of a patent on the basis of this application.

Signature



Date

23 October
2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Mr. N.R. Jennings
Tel: 020 7539 4200

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ELECTRO-MECHANICAL TRANSMISSION SYSTEMS

5 The present invention relates to a method of operating electro-mechanical transmission systems of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets
10 and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines.

Such transmission systems are of continuously variable transmission ratio and
15 are preferably of single regime type, that is to say they can provide all the necessary gear ratios without it being necessary to provide a clutch or the like to enable switching over to a further transmission system to obtain a portion of the desired range of transmission ratios.

20 An epicyclic gearset typically comprises a sun wheel in mesh with a plurality of planet wheels, which are rotatably mounted on a common carrier and are in mesh with an annulus wheel. However, it is possible under certain circumstances for an epicyclic gearset to have only two of these gear elements, whereby one of the sun wheel, planet wheels and annulus wheel is omitted.

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A transmission system of the type referred to above is disclosed in WO-A-01/94142. This known transmission system comprises an input shaft connected



to the planet carrier of the first gearset, which is also connected to the annulus wheel of the second gearset, and an output shaft connected to the planet carrier of the second gearset. The sun wheel of the first gearset is connected to the sun wheel of the second gearset. The rotors of the first and second electrical machines are respectively connected to the annulus wheel of the first gearset and the sun wheel of the second gearset. The electrical connections of the two stators are connected together via a control system.

In use, one of the electrical machines generally acts as a generator and transfers electrical power to the other electrical machine which acts as a motor. A proportion of the power transmitted by the transmission system is thus transmitted mechanically whilst a further varying proportion, which is typically up to about one third of the total, is transmitted electrically. Varying the electrical power transmitted between the two electrical machines, which may simply be achieved by varying the torque by means of the controller, which forms part of the control system, of one of the electrical machines, results in the torque available at the output varying at constant speed of the input.

The maximum electrical power transferred between the two electrical machines varies as the output speed varies and at least usually reaches zero at two different output speeds. When this power is zero, one of the electrical machines is stationary. In the known transmission the power transmitted between the two electrical machines is zero at a first finite output speed, i.e. an output speed greater than zero, and at a second higher output speed, whereby power is transmitted between the electrical machines at zero output speed. This means that the transmission with which the present invention is concerned provides a "geared neutral", i.e. the output may be arranged to be stationary when the input

is rotating.

5 The known transmission may have many different applications but it is thought to be particularly useful as the main propulsion transmission for a motor vehicle. A rechargeable battery may be provided to enable the vehicle to be of hybrid type, that is to say the electric battery may supply electric power to one of the electrical machines to increase the torque on the output shaft. At those times when excess power is available, electric power may be transmitted from one of the electrical machines to the battery to recharge it.

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One of the disadvantages of transmission systems of the type disclosed in WO-A-01/94142 is that they do not accelerate from rest as rapidly as is sometimes desirable, depending on the inertia of the load to which they are connected. As mentioned above, the transmission has a geared neutral and at zero output speed one electrical machine acts as a generator and its power is supplied to the other electrical machine, which is driven as a motor. If it is desired to accelerate from rest, the maximum possible torque may be required at the output shaft which is at zero output speed so that no work is performed. If one ignores the slight inefficiencies of the two electrical machines and the various meshing gearwheels, if no work is done at the output shaft, then no power is supplied to the input shaft by the vehicle engine. Accordingly, the torque applied to the output shaft is simply the sum of the torques on the two electrical machines. This means either that the vehicle will accelerate relatively slowly or that the electrical machines must have relatively high rated powers, in which event they will be unacceptably large, heavy and expensive. This problem can of course be alleviated to an extent by utilising the hybrid function of the vehicle, that is to say operating the controller to supply electric power from the battery to that

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electrical machine which is acting as a motor. This will increase the torque at that electrical machine and thus the torque on the output shaft. However, this increase is not very large and can only be for a relatively short period of time unless both the battery and the electrical machines are of a size which will make the transmission unacceptably heavy and expensive.

It is, therefore, the object of the invention to provide a method of increasing the torque applied to the output shaft, particularly when accelerating the output shaft, of an electro-mechanical transmission system of the type referred to without the transmission system or any of its components being unacceptably large, heavy or expensive.

According to one aspect of the present invention the method includes increasing the torque available at the output shaft by directing electric power from at least one of the machines to an electrical load comprising a dump resistor.

In practice, electrical power is likely to be taken only from that machine which is operating as a generator. However, it would be possible to cause both machines to operate as generators and to take electrical power from both of them.

According to a further aspect of the invention the method includes increasing the torque available at the output shaft by mechanically braking at least one of the electrical machines.

According to a further aspect of the invention the method includes increasing the torque available at the output shaft by causing one or both of the electrical

machines to operate less efficiently. If, as is preferred, the two electrical machines are of switched reluctance type, this may comprise altering the timing of excitation of one or both machines so that it operates at an efficiency substantially less than the maximum value that may be achieved and thus
5 operates in a manner similar to using a dump resistor.

According to yet a further aspect of the present invention the method includes increasing the torque available at the output shaft by directing electric power from at least one of the machines, preferably again that machine which is
10 operating as a generator, to an electrical load comprising a rechargeable electric battery.

According to a yet further aspect of the present invention there is provided a method of operating an electro-mechanical transmission system of the type
15 comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as
20 a motor or a generator, a third electrical machine, operable as a motor, and having its output shaft connected to one of the input and output shafts of the transmission system, all three machines having the electrical connections of the stators of all three electrical machines being connected together via a controller arranged to selectively control the flow of electrical power between the
25 machines, which method includes increasing the torque available at the output shaft by directing electric power from at least one of the machines, preferably that machine which is operating as a generator, to the third electrical machine.

The method will find particular application when the output shaft is rotating relatively slowly and is of particular value when accelerating the output shaft from a rest condition, in which the transmission system is in a geared neutral condition, in which the two electrical machines act as a generator and a motor, respectively.

Expressed in its broadest sense the invention embraces increasing the torque available at the output by extracting energy, in electrical or mechanical form, from the transmission system. Thus according to yet a further aspect of the present invention the method includes monitoring a signal indicative of the level of torque required at the output shaft and extracting energy in mechanical or electrical form from the transmission system when the said signal exceeds a predetermined value.

The method of the present invention is thus counter-intuitive and effectively the opposite of what is disclosed in the prior document referred to above in that precisely at the time that maximum torque is required at the output shaft, additional power is not introduced into the transmission system from a battery or the like but instead power is removed from the transmission system and this is found surprisingly to result in an increase in the output torque.

Clearly, some aspects of the method of the invention will reduce the overall efficiency of the transmission system. A practical system might therefore avoid dumping energy except when large output torques are required.

Thus in the method of the present invention, when, for example, a vehicle

incorporating a transmission system of the type referred to is stationary and the vehicle engine is idling, the controller is set so that one of the electrical machines is generating only a small amount of electrical power and this power is transmitted to the other electrical machine. The sum of the torques at the two electrical machines is very small and only this very small torque acts on the output shaft. Movement of the vehicle is prevented by frictional losses and/or application of the vehicle brake. If gentle acceleration is required, the controller is operated, in practice, by the engine management system which is nowadays commonly provided on motor vehicles and of which the controller will in practice form a part, to increase the electrical power transmitted from the generator to the motor. The torques of both the motor and generator will increase and the torque acting on the output shaft will be the sum of the torques at the motor and the generator and the torque applied by the engine to the input shaft to compensate for the mechanical and electrical losses within the transmission system, which are in practice inevitable. The controller is operated to produce whatever level of torque on the output shaft is desired. As the vehicle starts to move, an increasing amount of work is performed at the output shaft and an increasing proportion of the torque on the output shaft is derived from the vehicle engine. If, however, rapid acceleration is required, the controller is operated to increase the electrical power transmitted from the generator and at the same time energy is removed from the system, either mechanically, by braking some element of the system, or electrically, e.g. to a dump resistor. The power removed must be supplied by the engine which now adds torque into the system. The torque at the output is the sum of all the torques and therefore increases. Since the engine is running at low speed, it has a great deal of power available and it supplies to the input shaft an amount of power equal to the sum of that removed and the amount accounted for by



mechanical and electrical losses. The torque applied to the output shaft is thus increased by not only any increase in the torques at the motor and the generator but also the increase in torque on the input shaft.

5 The method of the invention is used similarly to increase the output torque when the vehicle or the like is already moving relatively slowly. However, in this case, instead of increasing the power supplied to the motor and removing power from the system, a proportion of the power supplied to the motor may be diverted, e.g. to a dump resistor. In this case, the torque at the motor will
10 decrease, and the power removed from the system will be additionally provided by the input shaft. However, since the input shaft will typically rotate very much more slowly than the input shaft, the torque increase on the input shaft will be substantially more than the torque reduction at the motor so that the sum of the torques, i.e. the torque available at the output shaft, is still significantly
15 increased.

Accordingly, the load may be accelerated from rest more rapidly than was previously possible. Alternatively, or expressed in other words, for a given maximum rate of acceleration from rest, the two electrical machines may be
20 smaller, lighter and cheaper than was previously the case.

The invention also embraces an electro-mechanical transmission system comprising two compounded epicyclic gearsets, having an input shaft adapted to be driven by a prime mover and connected to one gear element of one
25 gearset, an output shaft which, in use, provides output torque and is connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of

which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, and a mechanical brake arranged to brake at least one of the electrical machines.

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In a further aspect of the invention, the transmission system does not include a brake but includes a third electrical, which is operable as a motor and whose output shaft is connected to one of the input and output shafts and which is connected to at least one of the said two electrical machines to be electrically
10 powered thereby.

In a final aspect of the invention, the transmission system includes a sensor arranged to produce a signal indicative of the level of torque required at the output shaft, means for monitoring the said signal and means controlled by the
15 monitoring means for extracting power in mechanical or electrical form from the transmission system when the said signal exceeds a predetermined value.

Further features and details of the invention will be apparent from the following description of one specific embodiment which is given by way of example with
20 reference to the single accompanying drawing which is a highly schematic view of an electro-mechanical transmission system, which may be operated in accordance with the invention.

The transmission system shown in the single drawing comprises an outer
25 housing 10 accommodating two epicyclic gearsets 12 and 14. The first gearset 12 comprises a first sun wheel 16, which is fixedly carried by a shaft 18, which is mounted to rotate with respect to the housing 10 by bearings 20. A first

carrier 22 which constitutes a flywheel and is connected to an input shaft 23 carries a number, in this case three, of equispaced shafts 24, which carry respective first planet wheels 26. The first planet wheels 26 are in mesh with the first sun wheel 16 and with an internally toothed first annulus wheel 28.

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The first carrier 22 is connected via a radial flange 30 to the annulus wheel 32 of the second gearset. The second annulus wheel 32 is in mesh with a plurality of second planet wheels 34 carried by a second carrier 38. The planet wheels 34 are also in mesh with a second sun wheel 36 fixedly carried by the shaft 18.

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The second carrier 38 includes an externally toothed portion 40 which is in mesh with a gearwheel 42 connected to the output shaft 43.

The transmission system includes first and second electrical machines, which are capable of acting as both a motor and a generator. The machines are in this case of brushless and, specifically, switched reluctance type, though any type of machine could be used. The machines include respective first and second stators 44 and 46 which are fixed to the housing 10. The first stator 44 is sealed with respect to the flywheel 22 by means of an oil seal 48 and a similar oil seal 50 is provided between the output shaft and the outer housing. The first machine also includes a first rotor 52, which is connected to rotate with the first annulus wheel 28. The second machine includes a second rotor 54, which is connected to rotate with the shaft 18 and thus with the two sun wheels 16, 36.

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The stator connections on the two stators 44, 46 are connected via respective controllers 56, 58 of known type, which form part of an overall control system, to a common bus bar 60. The controllers will be connected, in use, to e.g. the engine management system of the vehicle in which the transmission is installed.

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They are used in known manner to control the electrical machines and the voltage applied to the bus bar 60 by that machine which is acting as a generator and thus to control the electrical power that is transferred between the two machines. This control is the means by which the output speed and thus the transmission ratio of the transmission system are varied in response to commands by the user, e.g. by the application of pressure to the brake or accelerator pedals. The bus bar 60 is also connected to a further controller 62, which is also connected to a dump resistor 64.

In use, the electrical power transmitted between the two electrical machines will vary with the power applied to the input shaft. At maximum rated power, the output speed cannot be zero and has a minimum value at a speed at which the power transferred between the electrical machines is at a first maximum. As the output speed increases, the electrical power transferred decreases until a first node point is reached at which the power transferred is zero. As the output speed continues to increase, the electrical power transferred progressively increases again but in the opposite direction, indicating that the two machines which were previously acting as a motor and a generator are now acting as a generator and a motor respectively. As the output speed continues to increase, the power transferred again reaches a second maximum and then decreases to zero again at a further node point. The power flow again reverses direction and rises to a further maximum. The remainder of the input power is of course transmitted mechanically through the gearwheels and not electrically. The so-called Node Span Ratio, which is the ratio of the output speeds at the two node points, is preferably in excess of 2 or 2.5 or even 3. As the input power decreases, the value of the maximum achievable range of transmission ratios increases dramatically, though the node span ratio remains substantially

constant.

In use, the input shaft of the transmission system would typically be connected to an automotive engine and the output shaft will be connected to a pair of driven wheels of a vehicle via a differential or the like. It will, however, be appreciated that the transmission system may have numerous different applications. If the transmission system is in the geared neutral condition and it is desired to accelerate rapidly, the controllers 56 and 58 are operated to substantially increase the power developed by that electrical machine which is operating as a generator and the controller 62 is operated simultaneously to dump power in the dump resistor 64. The torque acting on the input shaft 23 will increase to a value sufficient to compensate for the power transmitted to the dump resistor 64. The torque applied to the output shaft will be the sum of the torques on the two motor/generators and the torque on the input shaft. The transmission of electrical power to the dump resistor is desirable principally when a high rate of acceleration is required and then primarily only at zero and low output speeds.

In the preferred embodiment, a sensor (not shown) is provided which produces a signal indicative of the torque required at the output shaft. When the transmission system is fitted into a motor vehicle, this sensor may conveniently respond to the position of the accelerator pedal. This signal is monitored by the control system and only when its magnitude exceeds a predetermined level, thus indicating that a high level of torque is required at the output shaft, is the controller 62 operated to transmit power to the dump resistor 64.

CLAIMS

1. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes increasing the torque available at the output shaft by directing electric power from at least one of the machines to an electrical load comprising a dump resistor.
2. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes increasing the torque available at the output shaft by mechanically braking at least one of the electrical machines.
3. A method as claimed in Claim 2 in which only that electrical machine

which is operating as a generator is braked.

4. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes increasing the torque available at the output shaft by causing one or both of the electrical machines to operate less efficiently.

5. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator, a third electrical machine, operable as a motor, and having its output shaft connected to one of the input and output shafts of the transmission system, all three machines having the electrical connections of the stators of all three electrical machines being connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes increasing the torque available at the output shaft by directing electric power from at least one of the



machines which is operating as a generator to the third electrical machine.

5 6. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes increasing the torque available at the output shaft by directing electric power from at least one of the machines which is operating as a generator to an electrical load comprising a rechargeable electric battery.

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20 7. A method of operating an electro-mechanical transmission system of the type comprising two compounded epicyclic gearsets, having an input shaft driven by a prime mover and connected to one gear element of one gearset, an output shaft providing output torque and connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, which method includes monitoring a signal indicative of the level of torque required at the output shaft and extracting energy in mechanical or electrical form from the transmission system when the said signal exceeds a predetermined value.

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8. A method as claimed in any one of the preceding claims which includes accelerating the output shaft from a rest condition, in which the transmission system is in a geared neutral condition, in which the two electrical machines act
5 as a generator and a motor, respectively.

9. An electro-mechanical transmission system comprising two compounded epicyclic gearsets, having an input shaft adapted to be driven by a prime mover and connected to one gear element of one gearset, an output shaft which, in use,
10 provides output torque and is connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between
15 the machines, and a mechanical brake arranged to brake at least one of the electrical machines.

10. An electro-mechanical transmission system comprising two compounded epicyclic gearsets, having an input shaft adapted to be driven by a prime mover and connected to one gear element of one gearset, an output shaft which, in use,
20 provides output torque and is connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between
25 the machines and a third electrical machine, which is operable as a motor and whose output shaft is connected to one of the input and output shafts and which



is connected to at least one of the said two electrical machines to be electrically powered thereby.

- 5 11. An electro-mechanical transmission system comprising two compounded epicyclic gearsets, having an input shaft adapted to be driven by a prime mover and connected to one gear element of one gearset, an output shaft which, in use, provides output torque and is connected to one gear element of the other gearset, two electrical machines, the rotors of which are connected to respective gear elements of the two gearsets and each of which is able to operate either as
- 10 a motor or a generator and the stators of which are connected together via a controller arranged to selectively control the flow of electrical power between the machines, a sensor arranged to produce a signal indicative of the level of torque required at the output shaft, means for monitoring the said signal and means controlled by the monitoring means for extracting power in mechanical
- 15 or electrical form from the transmission system when the said signal exceeds a predetermined value.

